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Wood and Coal Cofiring in Interior Alaska: Utilizing Woody Biomass From Wildland Defensible-Space Fire Treatments and Other Sources

David L. Nicholls, Stephen E. Patterson, and Erin Uloth[1]

Abstract

Cofiring wood and coal at Fairbanks, Alaska, area electrical generation facilities represents an opportunity to use woody biomass from clearings within the borough's wildland-urban interface and from other sources, such as sawmill residues and woody material intended for landfills. Potential benefits of cofiring include air quality improvements, reduced greenhouse gas emissions, market and employment development opportunities, and reduction of municipal wood residues at area landfills. Important issues that must be addressed to enable cofiring include wood chip uniformity and quality, fuel mixing procedures, transportation and wood chip processing costs, infrastructure requirements, and long-term biomass supply. Additional steps in implementing successful cofiring programs could include test burns, an assessment of area biomass supply and treatment needs, and a detailed economic and technical feasibility study. Although Fairbanks North Star Borough is well positioned to use biomass for cofiring at coal burning facilities, long-term cofiring operations would require expansion of biomass sources beyond defensible-space-related clearings alone. Long-term sources could potentially include a range of woody materials including forest harvesting residues, sawmill residues, and municipal wastes.

Keywords: Biomass, energy, wildland-urban interface, coal, Alaska.

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[1] **David L. Nicholls** is a forest products technologist, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Alaska Wood Utilization Research and Development Center, 204 Siginaka Way, Sitka, AK 99835; **Stephen E. Patterson** is Assistant Director, Cooperative Forestry, Alaska Region State and Private Forestry, 3301 C Street, Suite 202, Anchorage, AK 99503; and **Erin Uloth** is a Presidential Management Fellow, Alaska Region State and Private Forestry, 3301 C Street, Suite 202, Anchorage, AK 99503.

Introduction

This paper explores the potential use of woody biomass as a supplemental energy source at one or more coal-fired electrical generating facilities near Fairbanks, Alaska. A major source of this biomass would be obtained from forest clearings in populated areas of the Fairbanks North Star Borough.

The Fairbanks North Star Borough of Alaska encompasses an area of 7,366 square miles (U.S. Census Bureau 2004) and has a total population of about 86,000, including the cities of Fairbanks (approximately 30,000 people), North Pole, and several other communities (fig. 1). When considered as one unit, Fairbanks North Star Borough is the second largest metropolitan area in Alaska. There are federal jurisdictions over the power plants on the two military bases, Fort Wainwright (army) and Eielson Air Force Base (air force and air guard). Other power plants within Fairbanks North Star Borough include Aurora Electric, serving the city of Fairbanks, and a power plant serving the University of Alaska-Fairbanks (fig. 2).

A concerted effort is now underway to reduce fuel loadings within the Fairbanks North Star Borough by using defensible-space clearings. To date, stems have been mechanically removed on approximately 250 acres of overstocked stands. This effort is expected to continue for 5 to 10 years on about 5,000 additional acres.

Biomass could be chipped on site, transported to local power facilities, and then burned alone or mixed with coal for burning.

In shearblading, all stems on a site are mechanically removed, and typically piled in windrows followed by burning. Smoky conditions can sometimes exceed state of Alaska allowable limits, potentially creating problems for neighbors. Treatments are generally done when the ground is frozen to improve shearing effectiveness and reduce soil displacement, which reduces smoke and erosion potential. When considering short-term aesthetic concerns prior to burning, shearblading and windrow piling of biomass can create unfavorable site conditions. In addition, there is an associated risk (and suppression cost) of windrow fires escaping to neighboring forests or residential areas. Alternatively, biomass could be chipped on site, transported to local power facilities, and then burned alone or mixed with coal for burning. Understory thinnings, often disposed of in area landfills, represent another source of biomass for cofiring.

This paper provides a preliminary overview of the potential for burning woody biomass and coal mixtures at Fairbanks area electrical generating facilities. It also evaluates some of the anticipated benefits and issues. Specifically, we address whether it is reasonable to consider woody biomass and coal

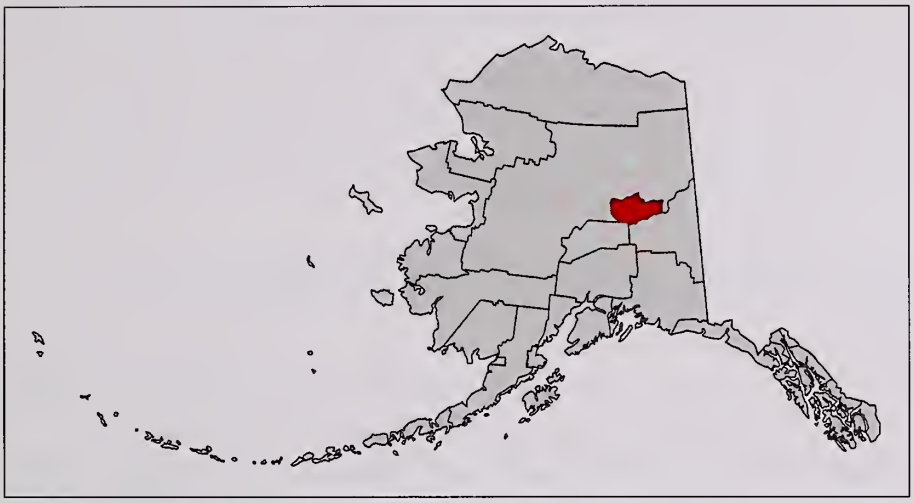

Figure 1—Fairbanks North Star Borough (shaded) within Alaska.

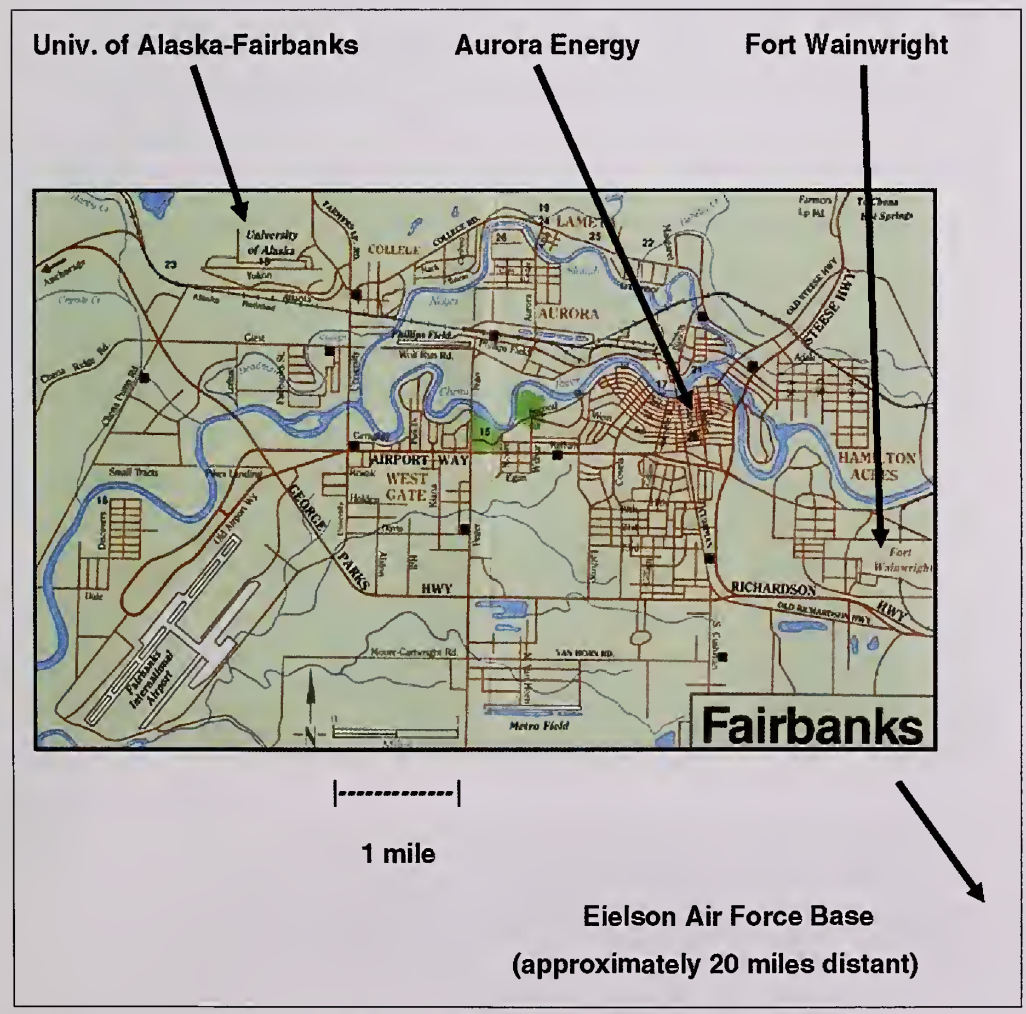

Figure 2—Location of coal burning electrical generation facilities in Fairbanks, Alaska.

to be cofired at any of four power plants near Fairbanks. We then address technical concerns of the managers of local coal-fired plants, as well as key forest management considerations. It is not within the scope of this paper to provide a detailed technical, engineering, or economic analysis of either cofiring or dedicated wood energy facilities.

Previous Cofiring Research and Experience in Alaska

Past research on wood-coal cofiring in Alaska has found that there is strong potential to use wood at ratios of up to about 22 percent of the total fuel mix (Sampson et al. 1991). Maintaining peak production at power plants could sometimes be difficult at higher levels of wood fuel because of the relative lower British thermal unit (BTU) content of wood chips. Further, power plant personnel would require a brief learning period to optimize fuel feed rates, grate speeds, and other combustion parameters for wood-coal mixtures. This is especially important for spreader-stoker combustion systems,[2] used by coal plants in the Fairbanks area. Sampson et al. (1991) also found that wood chips could be economically hauled up to 60 miles to an energy facility. It was recommended that wood not be burned during winter, when moving and mixing frozen chips with coal can be difficult.

In 1997, the Eielson Air Force Base, near Fairbanks, Alaska, began cofiring recycled paper, plastic, and smaller amounts of woodwaste with coal in their power plant. Biomass was processed through a cuber and then trucked to the powerplant railyard, where it was dumped into the coal receiving bin. No additional measures were used to mix the paper cubes with coal as they both have about the same density. Plant personnel have not noticed a problem with fuel segregation and have been generally satisfied with the performance of the biomass fuel. The cofiring program, which used up to 1,700 tons per year of biomass fuel, is scheduled to resume after being halted in 2004. The powerplant at Eielson Air Force Base used about 180,000 tons of coal in 2004.

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[2] In spreader-stoker systems, fuel is typically introduced mechanically or pneumatically into a combustion chamber, with finer fuels being burned in suspension, and larger particles being deposited and then burned on a grate that slowly moves across the combustion zone, discharging ash at the outfeed. Parameters such as particle size, fuel specific gravity, and moisture content are particularly important in these types of systems.

Previous Cofiring Research in Other Regions

Cofiring wood and coal has been considered at numerous test sites including Florida (Segrest et al. 2001), Kentucky (Ringe et al. 1998), New York, and Michigan. Studies of these and others indicate that cofiring can be implemented effectively under a wide range of operating conditions, combustion technologies, and fuel types (Robinson et al. 1998, Tillman 2000). Technical feasibility has been shown and constraints identified. However, Hughes (2000) indicated that in 2000, the technology was not economically feasible unless monetary incentives were provided.

Perspectives of Local Coal-Fired Electrical Plant Managers

Plant managers at four interior Alaska coal facilities were contacted to discuss the technical feasibility of cofiring wood and coal. All are cogeneration facilities, producing electricity and heat (fig. 2), and include:

- University of Alaska-Fairbanks
- Aurora Energy
- Fort Wainwright Army Base
- Eielson Air Force Base

Combined, they have approximately 85 megawatts of generating capacity, and consume approximately 600,000 tons of coal per year. Most managers were in general agreement that wood could be successfully cofired with coal under certain conditions, and offered the following observations:

- Wood particle size, moisture content, and fuel metering levels are key variables to consider. It will be important for wood to behave in a manner similar to coal during handling and burning. This will be particularly important for spreader-stoker systems.
- Burning material containing large proportions of foliage and bark, such as small-diameter black spruce (*Picea mariana* (Mill.) B.S.P.), will create additional challenges in fuel storage, handling, and combustion compared to clean woody chips (the material used in previous test burns [Sampson et al. 1991]).
- Relatively few equipment modifications should be needed to existing coal systems to burn wood biomass. The primary needs would be in fuel storage, handling, and conveying. Additional yard space may be required for storage of wood fuel. All of these modifications are viewed as minor when considering the range of equipment typically found in coal burning facilities.

Fuel mixing procedures will need to be carefully considered. Wood and coal could be mixed before storage, or wood and coal could be fed into combustors from separate fuel metering bins.

- Plant operators may need to fine-tune conditions such as fuel feed rate, grate speed, and other combustion parameters to account for the presence of wood in the fuel mix.
- Frozen wood burned during winter can cause problems with compaction and bridging within fuel storage and transfer areas. If wood were burned only during summer, operational challenges could be encountered during a yearly "start-up" period. In addition, biomass harvested during winter would need to be stored until the summer burning season, creating additional space requirements.
- Fuel mixing procedures will need to be carefully considered. Wood and coal could be mixed before storage, or wood and coal could be fed into combustors from separate fuel metering bins. The choice of fuel mixing procedure and the associated storage requirements will have a direct bearing on the economic feasibility of cofiring wood and coal.
- Long-term procurement contracts for wood fuel should be addressed. Supplies in addition to biomass from clearings will most likely be needed to justify the capital outlay and stabilize the supply of biomass for power plants.
- Delivered cost of coal will vary depending on BTU content, and whether coal is screened or unscreened, but will likely average $40 per ton for Fairbanks area facilities.

Bioenergy Advantages

Although coal has been a preferred fuel for large-scale electrical energy facilities, there are advantages to using wood fuel. Given the large volumes of coal burned (both within Alaska and nationally), if only wood residue from the forest products industry were cofired, it could supply 3 to 5 percent of the electrical energy generated in the United States (Hughes 2000). Several other benefits of wood are worth noting:

- Wood is a renewable energy source that makes no net contribution to carbon dioxide (CO_2) greenhouse gas emissions when trees regenerate, creating new biomass that can be used for energy.[3] Forests may also act as carbon sinks to the extent that new woody growth stores atmospheric

[3] Because trees are an active part of the global carbon cycle, burning wood for energy needs does not introduce additional CO_2 into the atmosphere. If carbon is not returned to the atmosphere by burning wood, it will ultimately return to the atmosphere via decomposition processes. This is compared to fossil fuel burning, which takes inactive, stored carbon and adds it to the total carbon active in the carbon cycle (Robinson et al. 2003).

CO_2. However, the benefits of increased forest growth and carbon storage must be weighed against increased fire risk, particularly with considering small-diameter, overstocked stands (Rapp 2004).

Using a sustainable wood resource to supply a portion of Alaska's energy needs in coal burning facilities may lead to incremental reductions in greenhouse gas emissions and could set the stage for future biomass development work. Biomass resources in Alaska and elsewhere may soon play an increasing role in carbon trading activities, receiving carbon offset credits for displacing fossil fuels (Sims 2003) while leading to market-driven solutions for greenhouse gas emissions (Fusaro, n.d.).

- Wood energy systems may require a larger labor force than coal-based systems. In the Fairbanks area, this could include added labor for harvesting, transportation, fuel storage, and handling of biomass. All of these activities would accrue benefits to local economies.
- Wood cofiring offers a variety of potential air quality improvements including reduced particulate, nitrogen compound, and sulfur compound emissions, but it is unlikely to be economically competitive for control in a credit market (Robinson et al. 2003). However, the financial benefits of reduced emissions should not be overlooked, especially in emerging energy markets where environmental service credits could be more closely regulated.
- A wide range of woody materials (including forest harvesting residues, municipal wastes, and wood products residues) destined for Fairbanks area landfills could be diverted to produce energy.

Delivered Fuel Costs of Coal and Biomass

We make the following assumptions in estimating delivered fuel costs:

- Harvesting cost: $150 per acre
- Volume of biomass: 20 tons per acre
- Chipping and loading cost: $4 per green ton
- Transportation cost: $0.23 per ton-mile
- Average one-way transportation distance: 60 miles
- Net heating value of biomass: 4,500 BTU per pound
- Net heating value of coal: 7,750 BTU per pound
- Delivered cost of coal: $40 per ton

Harvesting and Forest Management Considerations

Hazard risk assessments and fuel maps for the Fairbanks, Alaska, area are being prepared by the Alaska Division of Natural Resources, Division of

Forestry. Initially, most harvests will be in dense stands of black spruce. Typically, these stands have stems up to 6 inches in diameter and yield 15 to 30 green tons of biomass per acre.

Alaska Division of Forestry has evaluated several harvesting techniques and recognizes shearblading as having practical and economic advantages; however, there are potential environmental concerns. In shearblading, all stems on a site are mechanically removed, and typically piled in windrows followed by burning. Associated equipment, including tub grinders, loaders, and chip vans, could have negative environmental impacts. To date, approximately 250 acres in the Cash Creek drainage have been harvested, and in the near term, the Little Chena Drainage could provide another 2,400 acres of woody biomass.

The actual acreage cleared over the next few years could depend in part on whether financial incentives can be secured to help offset the approximately $150 per acre for harvesting and associated costs. If so, local entrepreneurs could find potential profit opportunities in chipping, loading, and transporting wood fuel to power plants. However, it is questionable that local businesses could operate profitably when paying these costs in addition to harvesting.

Transportation cost is estimated to be about $0.20 to $0.25 per green ton-mile. We use a value of $0.23 per ton-mile; however, there is little local experience or data to validate this estimate. The average transportation distance between wildland-urban interface (WUI) harvest sites and power plant locations is estimated to be 60 miles. Onsite chipping and loading is anticipated to be an additional $3 to $5 per green ton, but there are few examples of similar "in-woods" activities near Fairbanks that could be used to substantiate this. We estimated delivered wood fuel costs to be $35 per green ton, which was somewhat greater than delivered coal costs when evaluated on a dollar per BTU basis (table 1). Under these assumptions, coal would cost $2.58 per million BTUs, and wood fuel would cost $3.89 per million BTUs. Other estimates of wood fuel costs suggest that values close to $35 per delivered green ton would be realistic for whole-tree chips transported distances comparable to the Fairbanks WUI clearings.[4]

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[4] Atkins, D. 2005. Personal communication. Fuels for Schools Program Manager, U.S. Department of Agriculture, Forest Service, 200 E Broadway, Missoula, MT 59807.

Table 1—Estimated delivered energy costs (dollars per British thermal unit [BTU]) for coal and for woody biomass

Fuel type	Cost per delivered ton	Net energy content	Net energy content	Fuel cost
	Dollars	*BTUs per pound*	*Million BTUs per ton*	*Dollars per million BTUs*
Coal	40	7,750	15.5	2.58
Wood	35	4,500	9.0	3.89

About 100,000 green tons of biomass[5] from defensible-space clearings could be available for power generation in the Fairbanks area within the next 5 to 10 years. This relatively short timeframe would probably not be sufficient to amortize the investments needed to collect and harvest biomass, nor any plant improvements for fuel handling and storage. As such, longer term fuel sources could also include sawmill manufacturing residues, forest management residues (including thinnings), and urban forestry cuttings and tree removals. However, a significant step in the long-term supply is being able to find higher value uses for at least a portion of the harvested material. In addition to the forest biomass component, an unknown amount of wood from the municipal solid waste stream could also be available.

Longer term fuel sources could also include sawmill manufacturing residues, forest management residues and urban forestry cuttings and tree removals.

The expected biomass volumes would most likely not allow for substantial business investment in the range of harvesting equipment needed (including cutting, chipping, and hauling equipment). This scale of operation for WUI clearings near Fairbanks, Alaska, could include a small in-woods chipper (located at a centralized landing) and a dump truck. Alternatively, a chipper and concentration yard could be located at a coal facility with traditional logging trucks transporting stem material from woods to the plant. Slash and logs could be chipped immediately, or stored onsite and allowed to air dry, reducing moisture content (and increasing BTU content).

What "critical mass" would be needed for entrepreneurs near Fairbanks, Alaska, to profitably harvest and transport wood from WUI clearings to coal plants for cofiring? Could local equipment (possibly including trucks and fuel storage systems) already in use for other purposes be adapted for harvesting biomass? The answers to these questions are not clear; however, business

[5] Assumes harvests of 5,000 total acres with an average of 20 green tons per acre.

investment in harvesting and transportation equipment would need to be scaled appropriately to match available resources, and long-term biomass supplies would need to be secured. In other regions of the United States, small businesses dedicated to harvesting, chipping, and delivery have successfully provided fuel for applications such as heating college campuses (Kent 2005). In Chadron, Nebraska, a family business with 2.5 full-time-equivalent employees has sustained providing about 10,000 tons per year of wood chips over the past 14 years for the energy system at Chadron State College (see footnote 4). The fuel source at Chadron was local, overstocked stands, similar to the Fairbanks, Alaska, WUI. Given the tons per year of biomass expected from Fairbanks clearings, we expect employment and small business opportunities to be at least as great as those experienced in Chadron, Nebraska.

Considerations

There are apparent benefits to using a portion of the biomass from Fairbanks area clearings, woody municipal wastes, and sawmill residues as a supplemental energy source in coal plants. Past research in interior Alaska as well as success stories from other regions of the United States have demonstrated the feasibility of cofiring wood and coal under a range of operating conditions. There are several advantages for using woody biomass from the Fairbanks North Star Borough, when compared to other regions of the continental United States:

- The flexibility of four local coal-burning plants, all located relatively near harvest sites.
- Relatively short transportation distances from harvest sites to coal plants.
- Relatively gentle terrain, and the potential for low harvesting costs.
- Past successful test burns with wood and coal.
- Potential air quality improvements.
- Potential reduction of material to area landfills.

Over the next 5 to 10 years, defensible-space clearings within the Fairbanks area WUI could provide up to 100,000 tons of biomass, an amount that could easily supply one or more area coal-fired facilities with at least 10 percent of their fuel needs (by weight). Over the longer term, area sawmill residues and harvesting residues from forest management and urban forestry cuttings could also be included. An important consideration will be secure funding to harvest WUI acres, estimated at more than $150 per acre. Additional costs of transporting and storing biomass fuel will need to be weighed against the current market value of wood fuel to determine

profitability. Ten years from now (2015), an additional supply of hardwood fuel may be available within a 50-mile hauling radius of Fairbanks (Richmond et al. 1987). The Tanana Valley State Forest, near Fairbanks, may also be a substantial hardwood biomass resource (Alaska Department of Natural Resources, n.d.). Silvicultural prescriptions to enhance hardwood regeneration in mixed spruce forests would also reduce future fire risks while enhancing cover and forage for wildlife (Paragi 2004).

Little or no equipment modifications of existing combustion systems should be needed at coal plants to burn wood. However, some equipment modifications would likely be required for fuel storing, mixing, and conveying. Procedures for mixing coal and wood to achieve a uniform fuel would need to be developed. Further, plant managers may need to "tweak" fuel feed rates, grate speeds, and other operating conditions to optimize burning conditions for wood and coal mixtures.

Numerous environmental benefits could result from using wood for energy, including reduced sulphur and nitrogen emissions (compared to coal-only systems), as well as fewer greenhouse emissions given the renewable nature of wood fuel. Currently, many of these benefits are not easily quantified economically. By cofiring wood at several coal plants, Alaska would be taking a forward position on renewable energy as well as making incremental changes to reduce greenhouse gas emissions.

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters
Feet	.305	Meters
Acres	0.41	Hectares
Square feet	.093	Square meters
Square miles	2.59	Square kilometers
Cubic feet	.028	Cubic meters
Pounds	.454	Kilograms
Tons	907	Kilograms
Tons per acre	2.24	Tonnes or megagrams per hectare
Pounds per cubic foot	16.03	Kilograms per cubic meter
Megawatts	3.42×10^6	British thermal units per hour

Literature Cited

Alaska Department of Natural Resources, Division of Forestry. [N.d.]. New growth—prospectus for the forest products industry, interior Alaska. Prepared for Governor Murkowski by the Alaska Department of Natural Resources, Division of Forestry, 550 W Seventh Ave., Anchorage, AK 99501-3566. 11 p.

Fusaro, P.C. [N.d.]. Green trading: the status of green trading markets. [Place of publication unknown]: [Publisher unknown]. Chapter 1.

Hughes, E. 2000. Biomass cofiring: economics, policy and opportunities. Biomass and Bioenergy 19: 457-465.

Kent, J. 2005. Nebraska College promotes wood chips as cheap, clean energy source. www.voanews.com. (December).

Paragi, T. 2004. Studying the value of fuels management for wildlife habitat in interior Alaska. Western Forester. 49(3): 14-15.

Rapp, V. 2004. Western forests, fire risk, and climate change. Science Update 6. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 11 p.

Richmond, A.P.; Sampson, G.R.; Gasbarro, A.F. 1987. Estimation of potential timber volume in the Tanana Valley available for conversion to wood chip fuel. Report 86-11. Fairbanks, AK: University of Alaska-Fairbanks, Agricultural and Forestry Experiment Station. 53 p.

Ringe, J.M.; Graves, D.H.; Reeb, J.E. 1998. Woodwaste biomass cofiring with high sulphur coal for power generation in Kentucky: a case study. Forest Products Journal. 48(4): 88-93.

Robinson, A.; Baxter, H.; Junker, H. [et al.]. 1998. Fireside issues associated with coal-biomass cofiring. Golden, CO: National Renewable Energy Laboratory. 11 p.

Robinson, A.L.; Rhodes, J.S.; Keith, D.W. [et al.]. 2003. Assessment of potential carbon dioxide reductions due to biomass–coal cofiring in the United States. Environmental Science and Technology. 37(22): 5081-5089.

Sampson, G.R.; Richmond, A.P.; Brewster, G.A. 1991. Cofiring of wood chips with coal in interior Alaska. Forest Products Journal. 41(5): 53-56.

Segrest, S.A.; Rockwood, D.L.; Stricker, J.A.; Alker, G.R. 2001. Partnering to cofire woody biomass in central Florida. In: Proceedings, 5th biomass conference of the Americas. [Place of publication unknown]: [Publisher unknown]. 2 p.

Sims, R.E.H. 2003. Climate change solutions from biomass, bioenergy, and biomaterials. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Invited Overview 5: 28 p.

Tillman, D.A. 2000. Biomass cofiring: the technology, the experience, the combustion consequences. Biomass and Bioenergy. 19: 365-384.

U.S. Census Bureau. 2004. State & county quick facts, Fairbanks North Star Borough, Alaska. http://quickfacts.census.gov/qfd/states/02/02090.html. (November 7, 2005).

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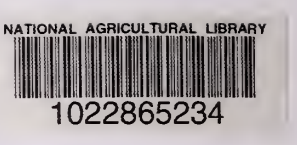
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